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Notes

Nearshore benthic blooms of filamentous green algae in Lake Baikal

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ABSTRACT

For the first time, species of the genus *Spirogyra*, non-typical of the open nearshore waters of Lake Baikal, formed algal mats with *Ulothrix zonata*, *Ulothrix tenerrima*, and *Ulothrix tenuissima* near the village of Listvyanka, Russia. Normally widely distributed in the 0- to 1.5-m depth range, the growth of *U. zonata* was now evident and dominant (63% of the biomass) in the 2- to 5-m depth range. The overgrowth of the lake bottom by filamentous green algae, changes in distributional boundaries, the emergence and mass development of species of the genus *Spirogyra*, the presence of the eutrophic diatom indicator *Fragilaria capucina* var. *vaucheriae*, elevated abundances of coliform bacteria, and elevated levels of nutrients suggest an early stage of cultural eutrophication in the nearshore of Lake Baikal near Listvyanka, a popular tourist destination. The unusual abundance of *Fragilaria* associated with the filamentous green algae consisted of long-ribbon colonies of *F. capucina* var. *vaucheriae*, a eutrophic species, wound around the filamentous green algae, enhancing the dense algae mats. Historically dominant species, such as *Didymosphenia geminata*, *Tetraspora cylindrica* var. *bullosa*, and *Draparnaldioides baicalensis* typically observed at deeper depths of Lake Baikal, are now subdominants or minor species in the nearshore along the shoreline near Listvyanka.

Introduction

Vegetation plays an important role in functioning and self-purification of aquatic environments, determines trophic status, and serves as an indicator of anthropogenic effect (Pourriot et al., 1995; Smith et al., 2006). Intense economic activity is often associated with an increase in "nutrient pollution", and particularly phosphorus load, to freshwater aquatic ecosystems and contributes to a gradual disturbance of both structural and functional organizations of ecosystems (Puzachenko, 1989; Vinberg, 1960). As a result of nutrient pollution in freshwater and marine environments (Auer et al., 2010; Depew et al., 2011; Higgins et al., 2005; Nozaki et al., 2003; Ostendorp et al., 2004; Pokrovskaya et al., 1983; Smith et al., 2006), a succession of plant communities and blooms of green algae may occur.

Unlike the European lakes and North American Great Lakes, the anthropogenic or cultural eutrophication of the waters of Lake Baikal, Russia, is a recent phenomenon associated with the development of the tourism industry. Over the past century in Lake Baikal, there have been no recorded occurrences of benthic mats of filamentous green algae (Dorogostaisky, 1906; Izhboldina, 1990; Meier, 1930; Skabichevsky, 1934) until the summer of 2011 near the village of Listvyanka. The village of Listvyanka with a population of about 2000 people is located on the shore of Lake Baikal, Russia. With over 350,000 tourists annually visiting the village surroundings in recent years, recreational use of the shoreline and of the nearshore areas of the lake has increased. Unfortunately, the village and numerous small-boat marinas do not have a centralized wastewater treatment plant. It is now apparent that the existence of a primitive wastewater treatment infrastructure has likely negatively affected the coastal zone of Lake Baikal.

The aim of this study was to evaluate the current benthic plant communities of the Lake Baikal nearshore zone in areas where elevated nutrient loads occurred and to determine the distribution and boundary of the overgrowth of filamentous benthic green algae.

Material and methods

Field studies

In July–August of 2011, a reconnaissance survey of benthic plant communities in the nearshore zone of Listvennichny Bay, Lake Baikal, was undertaken (Fig. 1A). Samples were taken along 100-m transects perpendicular to the lake-bottom contours to a depth of 10 m. Transect

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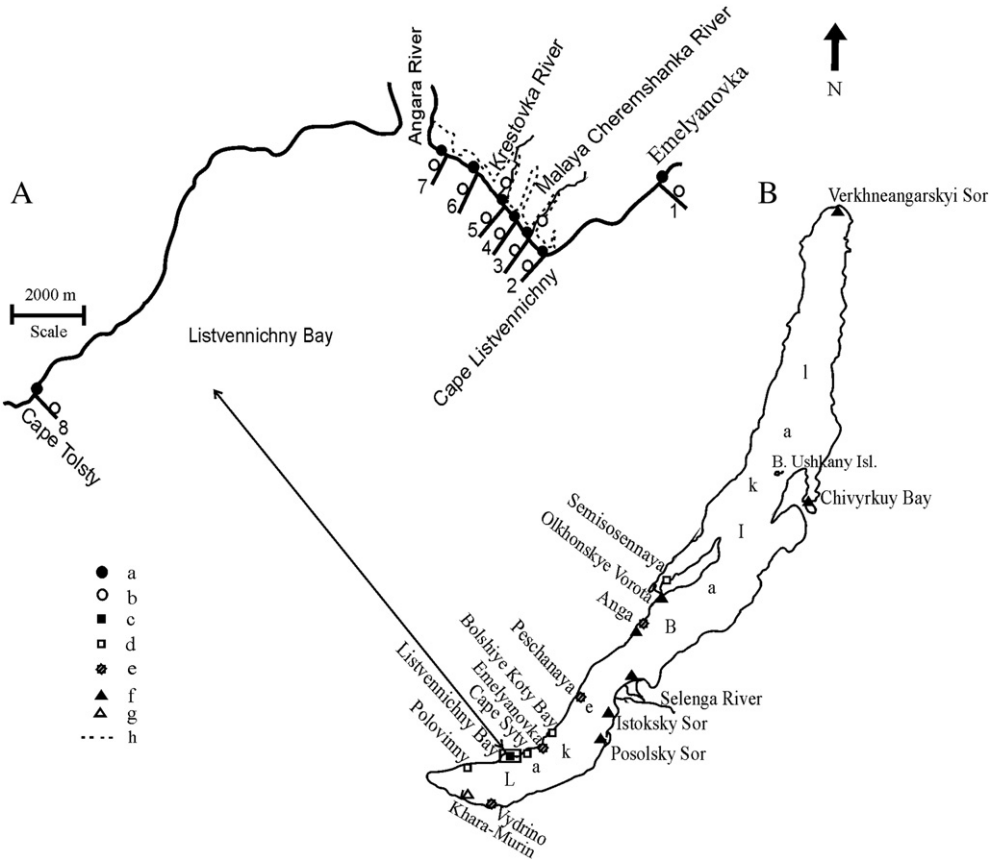

Fig. 1. Map of Listvennichny Bay (A) and the nearshore zone of Lake Baikal (B) showing sampling sites and locations where *Spirogyra* was observed. Survey transects are labeled 1 to 8. Symbols on map are explained by legend at lower left: a = shallow groundwater sample sites. b = water sample sites: Krestovka and Malaya Cheremshanka Rivers, near-bottom layers (3-m depth), and the lake surface (0 m). c = blooms of *Spirogyra*. d = filaments of *Spirogyra* not found. e = singular filaments of *Spirogyra* occurrence in Lake Baikal in 2011. f = occurrence of *Spirogyra* in Lake Baikal (from 1925 to 1990 by Izhboldina, 2007). g = absence of *Spirogyra* in 1975–1988 (Izhboldina's unpublished data on monitoring of benthic flora at site Khara-Murin). Dashed line (h) is the boundary of Listvyanka village.

1 (Emelyanovka) was 5 km to the northeast of Cape Listvennichny. Transects 2 to 7 were in the nearshore adjacent to the village of Listvyanka. Transect 5 was near the mouth of the Krestovka River which flows through the densely populated Listvyanka (Fig. 1A). Transect 8 was at Cape Tolsty west of Listvyanka (Fig. 1A). The bottom in this area was covered with boulders and sand.

Water sampling

To evaluate anthropogenic effects on Lake Baikal, water was sampled with 50-mL and 500-mL syringes for nutrients and bacteria. River water was sampled 100 m upstream from the mouths of the Krestovka and Malaya Cheremshanka Rivers while lacustrine near-bottom (at a depth of 3 m) and surface water samples (0 m) were collected at eight sites (Fig. 1A) 70 m off the lake shore. Shallow groundwater samples were taken from 30- to 50 cm holes dug in the ground 1.5 to 2 m inland from the water edge above the shoreline at each location (Fig. 1A). Only one sampling and analysis were performed at each site because of financial constraints.

Mapping of vegetation

To identify distribution boundaries of filamentous benthic green algae, scuba divers estimated vegetation abundance (semi-quantitative estimates) visually along Transects 1–8 every 10 m on the 100-m transect using a six-point scale (Abakumov, 1983):

a. 6 points — very abundant species, cover > 90%;
b. 5 points — abundant, 70–90% cover;
c. 4 points — many individuals, 50–70% cover;
d. 3 points — 30 to 40% cover;
e. 2 points — individuals small in number, 10–30% cover; and
f. 1 point — very few individuals, up to 10% cover.

Qualitative sampling of vegetation

Qualitative samples (8) were collected by scuba divers from each transect in Listvennichny Bay to characterize diversity of benthic flora. In addition, 16 qualitative samples were collected in September in the nearshore zone of the southern and central basins of Lake Baikal (Fig. 1B).

Quantitative sampling of vegetation

Quantitative benthic samples were collected at the reference site near Emelyanovka (Transect 1) and at the site of high anthropogenic activity located near the mouth of the Krestovka River (Transect 5) in Listvennichny Bay (Fig. 1A). Replicate vegetation (meio- and macro-algae and submerged macrophytes) samples (0.16 m^2 frame, n = 3) were collected by scuba divers from two depth zones (from rocky and sandy substrates between 0 to 1.5 m and between 2 to 5 m), placed in bags, and on the shore placed into flat-bottomed containers (30 × 50 × 10 cm). Submerged macrophytes (higher vascular plants) were cleaned from epiphytes by brushing, dried on filter paper, and placed in the herbarium for further identification in the laboratory. Meio-algae (>0.5 mm and <2 mm) and macro-algae (>2 mm) were also removed from stone surfaces by brushing and placed evenly onto the bottom of the large containers. One eighth of the sample